PATENT APPLICATION

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In Re the Application of: MAYOR	) Group Art Unit: 3662
Serial No.: 10/804,863	) Examiner: ALSOMIRI, Isam A.
Filed: 03-19-2004	)
Confirmation No.: 7656	) DECLARATION OF SCOTT SPULER
Atty. File No.: 50139-00001	)
For: "HIGH PULSE ENERGY, EYE-SAFE LIDAR SYSTEM"	)

Dear Sir:

I, Scott Spuler, declare as follows:

1. I am a Research Engineer at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, and am one of the inventors of the above-identified patent application. I received a Masters Degree and a Ph.D., each in Engineering Systems/Applied Optics, from the Colorado School of Mines in Golden, Colorado. Prior to that, I received a Bachelors Degree in Civil/Environmental Engineering from Virginia Tech.

2. Since 2002, I have worked in the field of Optical Research and Development at NCAR, one of the world's premier centers for atmospheric research. In particular, my research has focused on laser-based instrument systems including eye-safe lasers. Based on my education and work experience, I am familiar with the state-of-the-art in laser systems and am skilled in this field.

3. I have reviewed the above-identified patent application, including the pending claims that are attached as Exhibit 1. I have also reviewed the Examiner's Action dated July 11, 2008, as

well as the materials cited by the Examiner. For the reasons set forth below, it is my opinion that the claimed invention would not have been obvious to one of ordinary skill in the art, as of March 19, 2007 (the filing date of the above-identified application), based on the materials cited by the Examiner.

4. The claimed invention relates to a lidar system that includes, among other things, a relatively high pulse energy of at least about 100 mJ/pulse and a relatively high pulse repetition frequency of at least about 10 Hz, all in an eye-safe system. It is respectfully submitted that the Examiner has not fully appreciated the importance of or the difficulty of achieving this combination of features.

5. The noted combination of features enables the lidar system to operate in a scanning mode to effectively monitor a significant volume of atmosphere in substantially real time. For example, the claimed lidar system has been deployed adjacent to the Pentagon in Virginia to identify, for security purposes, any suspicious plumes of aerosols that that may appear in the atmosphere. A number of desired attributes of such a system will be readily apparent. First, such a system needs to have sufficient range to allow for early identification of any suspicious plumes, thereby allowing sufficient reaction time before the plume affects critical areas/personnel. Relatedly, the time for acquiring an image of the volume of atmosphere being monitored should be sufficiently short so as to realize the noted early warning benefits. In addition, particularly given the proximity to Reagan National Airport, the system needs to be eye-safe so as to avoid hazards to pilots, passengers and others.

6. These desired attributes are directly associated with the parameters specified in the claims. In particular, the relatively high pulse energy, in combination with high optical efficiency (e.g., matching of the angle of divergence to the field of view as set forth in the claims), allows for long range imaging based on the return signal of a single pulse or small number of pulses. The relatively high pulse repetition frequency enables rapid construction of a composite image from a number of exposures. In this regard, an image for a significant volume of atmosphere can be obtained by scanning the lidar system in a raster pattern while obtaining a series of exposures. To rapidly construct such an image requires both that each exposure can be

obtained quickly (relatively high pulse energy) and that the interval between exposures is short (relatively high pulse repetition frequency). These attributes need to be achieved while maintaining eye-safety (wavelengths of 1.5 – 1.8 microns). While each of these attributes is thus associated with one of the noted parameters, the parameters are also interrelated, e.g., both pulse energy (more accurately intensity) and wavelength are related to eye safety.

7. Unfortunately, after we had recognized the desirability of such a system and identified the desired parameters, it became clear that no suitable transmitter existed. Specifically, there was no suitable laser that could directly generate an appropriate beam having the desired qualities within the noted wavelength band. Moreover, there were significant obstacles to using a source laser of a different wavelength and Raman shifting the beam to provide an output having the desired parameters. Those difficulties included achieving previously unobtainable wavelength shifting efficiencies and designing a Raman cell that could process beams of high intensity without sooting and fouling of the optics.

8. It took great time, effort and expense for our team to realize the solution that is described in this application. The solution was achieved by mating a selected laser source with a novel methane Raman cell. The Raman cell uses a folded optical path for enhanced optical efficiency. Optics carefully control the beam width within the cell and internal reflectance elements (e.g., prisms) are used to fold the optical path without path overlap to reduce or substantially avoid sooting. Additionally, a system was devised for controlled circulation of the methane to rapidly remove the heated methane from the beam path and improve the quality of the Raman shifted beam. A seed laser is used in conjunction with the source laser to enhance shifting efficiency and Brewster angle configured optics further optimize performance. The result is that the transmission components yield an eye-safe beam having, we believe, a previously unachieved combination of pulse energy and pulse repetition frequency for the desired wavelength range. As discussed above, these parameters enable applications including substantially real-time scanning-based imaging of significant volumes of atmosphere.

9. The Examiner argues that the claimed subject matter could be achieved by combining third party devices that individually achieve one or more of the desired parameters. This

argument is based on a fundamental misunderstanding of the technology. In particular, the Examiner cites Segre, et al., U.S. Patent No. 3,963,347 ("Segre") as disclosing a laser with a pulse energy of 100 mJ/pulse. The Examiner then cites Guch Jr., et al, U.S. Patent No. 6,580,732 (Guch") as disclosing a different laser that can operate at a frequency in the hundreds of Hz. Finally, the Examiner simply asserts, without any explanation as to how and without any apparent understanding of the issues involved, that the systems of Segre and Guch could be combined to yield the claimed invention. As discussed below, Segre and Guch do not disclose the claimed invention.

10. First, it must be noted that the Examiner's argument as stated is a nonsequitor. The Examiner states that it "would have been obvious to modify Segre to use the transmitter of Guch..." However, such a system would not yield the claimed subject matter. Guch discloses a 1.57 μm laser operated at high frequencies, but that laser does not have a pulse energy of anywhere near 100 mJ. What the Examiner presumably means to suggest is that the laser of Segre, which the Examiner asserts is a 100 mJ/pulse laser, should be modified to operate at a pulse repetition frequency of at least about 10 Hz as required by the claims.

11. However, Segre does not disclose a 100 mJ/pulse laser and the laser it does disclose could not be made to operate at a pulse repetition frequency of at least about 10 Hz. The Examiner cites a background discussion in Segre about eye-safety standards for disclosing a laser with pulses of 100 mJ. It is unclear what, if anything, the background reference to lasers "operated in the 100 millijoule range" discloses. Even if that is a cryptic reference to a 100 mJ/pulse laser, that is not what Segre teaches should be used in his ceilometer. Rather, Segre teaches that the transmitter output is pulses "of 30 nanosecond halfwidth and approximately 1 megawatt peak power" thus defining a pulse energy of much less than 100 mJ/pulse. If Segre, et al. were aware of a 100 mJ/pulse eye-safe laser, they chose not to use it in their ceilometer.

12. What Segre does disclose is an Erbium laser. Although we are aware of a report of an Erbium-glass (Er:glass) laser developed to produce high energy pulses – up to 100 mJ – at 1.5 microns for determining ocular damage thresholds (see, Lund, et al. "Occular hazards of the Q-switched erbium laser," Investigative Ophthalmology, 463-470 vol. 9 (1970), attached as Exhibit

3) the resultant beam quality of such a laser is poor. Long distance propagation, as required for lidar applications, of poorly behaved beams is extremely inefficient. Furthermore, the poor thermal conductivity and the relatively large amount of flash lamp pump energy required create high energy pulses from Er:glass severely limits its pulse repetition frequency and the laser cannot be fired more than once every few seconds. See, Wong, et all. "High-energy hybrid Raman optical parametric amplifier eye safe laser source," Applied Optics, 1686-1690, vol. 9 (1994), attached as Exhibit 2. These restrictions limit Er:glass to applications that require only low pulse energies (e.g., eye-safe rangefinders which have strong reflections from clouds or hard targets) or where rapid pulse repetition is unnecessary (e.g., investigation of eye-damage thresholds). The fundamental nature of the Er:glass laser makes it unsuitable for use in high-energy lidar applications (e.g., those which rely on weak reflections from distributed aerosol targets). Therefore, where high repetition rate (10 Hz or greater) and high pulse energy (100 mJ or greater) is required – one much employ a Nd:YAG laser which is wavelength shifted to 1.5 μm by means of a Raman cell or a parametric oscillator. Accordingly, the Erbium laser of Segre, even if it was a 100 mJ/pulse laser (which it is not), cannot be modified to operate at a pulse repetition frequency of at least 10 Hz as the Examiner has suggested.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Date: 1/08/2009

Scott M Spuler
Scott Spuler

Ocular hazards of the Q-switched erbium laser

David J. Lund, Maurice B. Landers, George H. Bresnick, James O. Powell, Jack E. Chester, and Charles Carver

The threshold for ocular damage was determined in owl monkeys with the use of a Q-switched erbium-glass laser at 1.54μ constructed in the laboratory. Ocular damage was limited to the cornea and characterized by localized opacification of the epithelium and stroma. All exposures to energy densities greater than 30 j./cm.² produced injury. The median level for damage occurred at 21 j./cm.², and no injury could be detected below 17 j./cm.². Comparison with threshold values for ocular damage by Q-switched lasers operating in the visible and near visible portion of the spectrum shows that the erbium laser offers promise as a relatively "safe laser."

Key words: necrosis of cornea due to radiation, radiation injury, radiation intensity, lasers, experimental results, histopathology, monkeys.

Because of the serious ocular threat posed by laser devices operating in the visible portions of the spectrum, less hazardous laser systems are being sought by both the civilian and military communities. One approach is to utilize lasers that operate in spectral regions where the ocular media are relatively opaque to the incident radiation. In this respect the erbium laser offers a theoretical advantage based upon its emission spectrum in the infra-red.[1] Depending upon the host material employed, the emission wavelength of erbium varies from 1:53μ in glass to 1.64μ in yttrium-aluminum-garnet. The transmission of the eye at the erbium wavelengths is quite low (Fig. 1). Based upon these considerations a series of experiments were conducted to study the ocular effects of the Q-switched erbium laser.

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Methods

An erbium laser was constructed in this laboratory to deliver Q-switched laser pulses at 1.54μ. The dearth of erbium laser rods of even moderately good quality seriously restricted the design technique. The resulting erbium-glass laser consistently delivered up to 100 mj. of Q-switched energy in a single 50 nsec. pulse. Between 100 and 200 mj. output double pulsing occasionally occurred, yielding two 50 nsec. pulses separated by 200 nsec. Because of the quality of the laser rod, the beam cross section was quite irregular.

An elliptical cavity was used to couple the linear flash lamp to the laser rod. Q-switching was accomplished by a rotating prism driven at 20,000 r.p.m. and electronically synchronized to the flash lamp. A three-element quartz resonant reflector with a reflectivity of 65 per cent was used as the output mirror. A sapphire optical flat inserted in the resonant cavity at the Brewster angle polarized the laser output. This was required because polarization-dependent beam splitters were used in the delivery-detection system. The separate components were mounted on an optical bench yielding a total resonator length of 50 cm. A pulse-forming network consisting of 1300μf capacitance in series with 850μh inductance provided a 3.5 msec. pulse through the flash lamp. Triggering was accomplished through an inline trigger transformer.

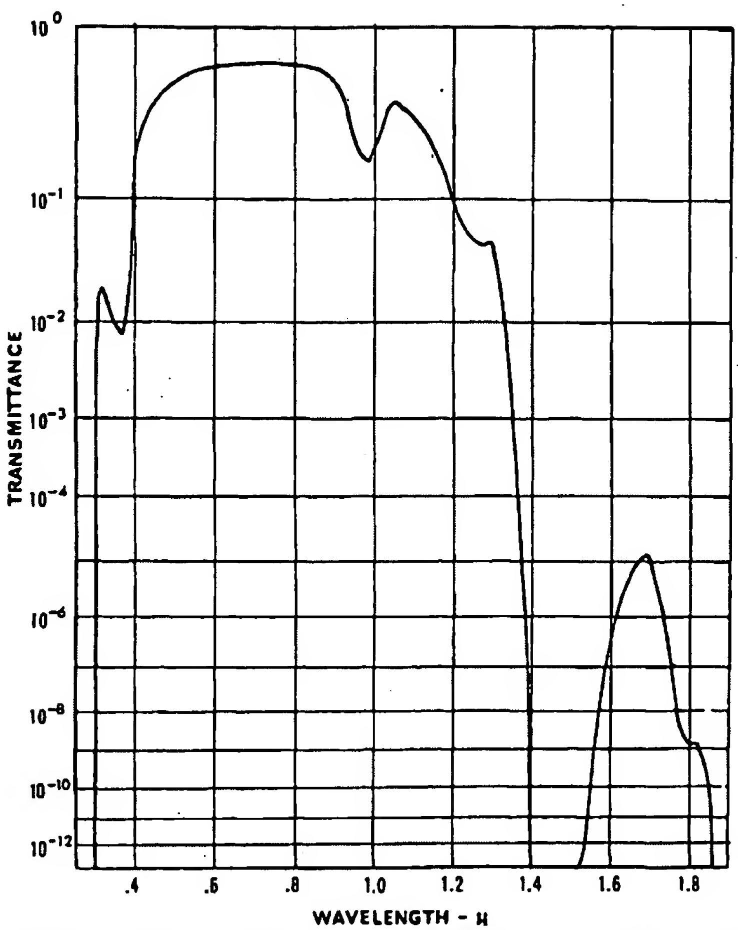

Fig. 1. Spectral transmittance through human eye. Between 0.3 and 1.3μ, the curve is based on measurement of human ocular tissue[2] Beyond 1.3μ, the transmittance is that of a 2.2 cm. layer of pure H_2O.

A detection system and a delivery system to couple the laser energy into the eye of the experimental animal were constructed as shown in Figs. 2 and 3. A low-power helium-neon laser beam was coupled into the delivery system through a beam splitter and carefully aligned to be colinear with the erbium laser beam, thus facilitating aiming and alignment of the system. After passing through attenuating and focusing optics, the erbium laser beam was limited by an aperture 2 mm. in diameter. Immediately beyond this aperture, a beam splitter directed a portion of the energy to a diffuse reflecting surface where it was monitored by calibrated detectors. An indium-arsenide photodiode measured the duration and number of output pulses and a germanium photodiode with an integrating network measured the energy. The portion of the beam passing through the beam splitter was incident upon the cornea of the experimental animal. Calibration of the detection system was accomplished by placing a TRG 100 Ballistic Thermopile in the eye-exposure position and comparing the photodiode output to the thermopile output. This technique compensated for the peculiarities of the aperture, beam splitters, and detectors by utilizing them in calibration exactly as they were used in measurement. The calibration was checked immediately before

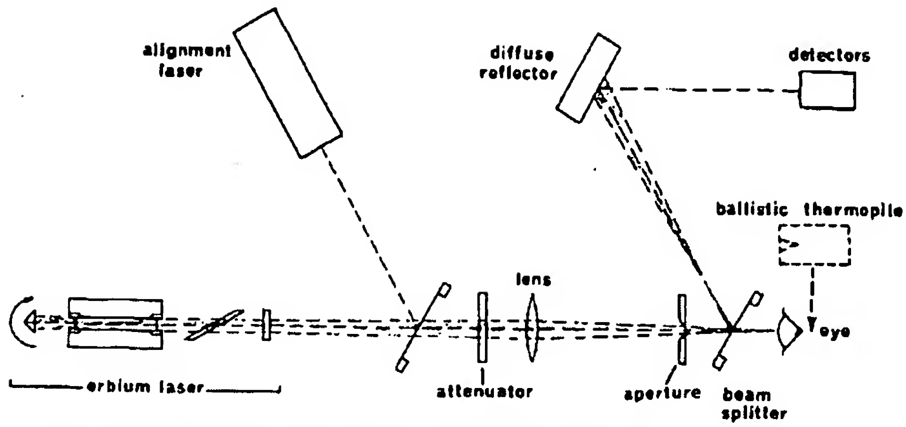

Fig. 2. Schematic diagram of the erbium experimental configuration.

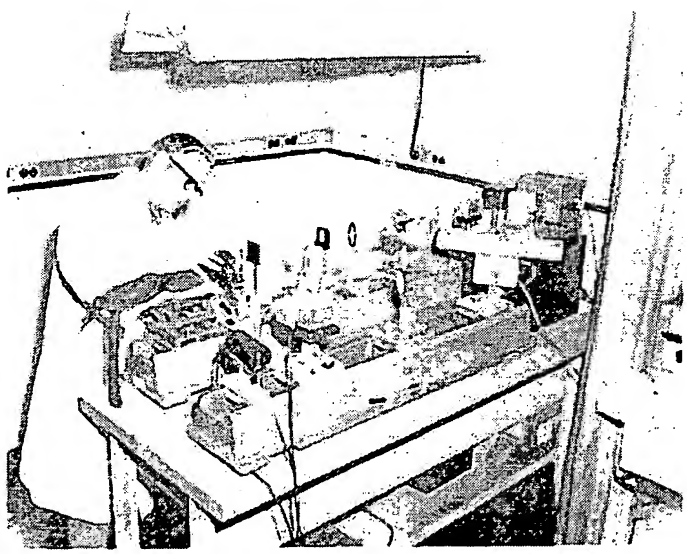

Fig. 3. Erbium experimental apparatus showing owl monkey positioned for exposure.

and after each animal experiment, giving results reproducible to ±10 per cent over the experimental period.

The animals used in these experiments were owl monkeys *(Aotus trivirgatus)*. Preanesthetic medication consisted of a sedative dose of phencyclidine hydrochloride (0.25 mg. per kilogram) intramuscularly, and atropine sulfate (0.2 mg.) subcutaneously. Anesthesia was induced with sodium pentobarbital (approximately 5 mg. per kilogram) via the saphenous vein. The pupils were dilated with phenylephrine hydrochloride (10 per cent) combined with cyclopentolate hydrochloride (1 per cent). Sutures of 3-0 silk were placed in the upper eyelids to facilitate their manipulation. Physiologic saline was used to prevent drying of the cornea.

Immediately before exposure, the eyes were carefully examined by slit lamp biomicroscopy and ophthalmoscopy, and any abnormal eye was

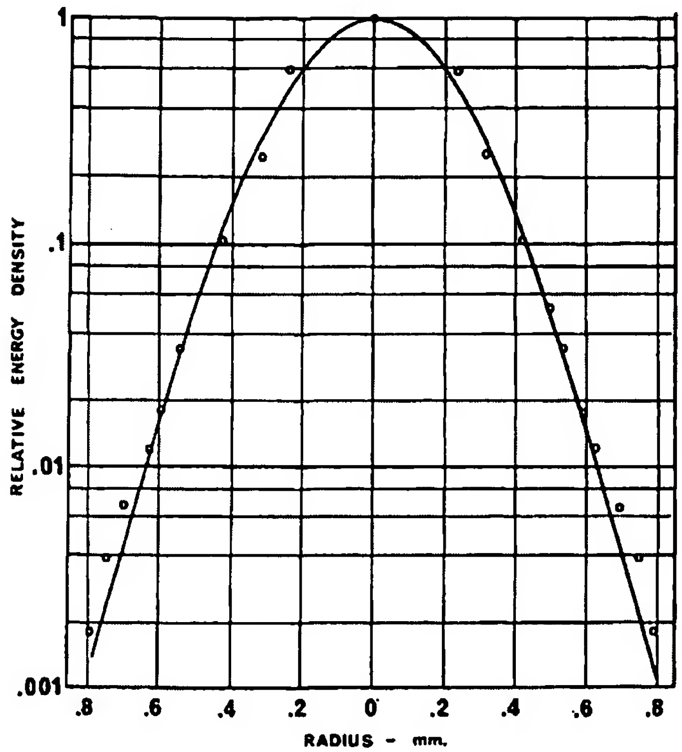

Fig. 4. Profile of the focused erbium laser beam showing experimental data points and a theoretical Gaussian curve.

rejected. The animal was placed in position in the delivery system and irradiated. Each corneal exposure site was examined immediately, and detailed biomicroscopy and ophthalmoscopy were performed at 30 to 60 minutes following exposure. Several eyes were observed at 1 day, 7 days, and 3 weeks following exposure.

Pathologic examination was performed on all eyes. The eyes were enucleated either immediately or from 1 to 14 days following exposure and fixed for 24 hours in 10 per cent formaldehyde. Serial sections of paraffin-embedded specimens were stained with hematoxylin and eosin and examined by light microscopy.

Two techniques of exposure were utilized. In the first series of experiments the direct output beam of the laser was employed without intervening optical lenses; a total of 15 exposures were placed in 5 eyes. In the second series of experiments a lens was used to focus the beam onto the cornea of the experimental animal for a total of 41 exposures in 14 eyes. In order to define the threshold level for damage, it was necessary to determine the peak energy density within the focused beam. This posed the problem of measuring the characteristics of the beam cross section at the focus of the lens. A technique employing exposed Polaroid film was used for this purpose. When impacted by laser radiation, the emulsion was burned from the film where the laser energy density exceeded a certain value. The film was subjected to a series of exposures with the laser at constant output, but with the beam attenuated in step-wise fashion by calibrated neutral density filters. Measurement of the diameter of the progressively decreasing spot size allowed the relative energy density profile to be plotted (Fig. 4). The beam at the focus was found to be approximately Gaussian. If the beam is assumed to be Gaussian, it is possible to calculate the peak energy density. For the purpose of computation the diameter of the beam spot is taken to be that diameter at which the relative energy density falls to a value $1/e$ of the peak value. The peak energy density is then the total measured energy divided by the area of the spot so defined.

Fig. 5. Photograph of a fresh corneal lesion produced with the Q-switched erbium laser at 45 j./cm.². Note the localized opacification of the epithelium, Bowman's membrane, and stroma with radiating folds in Descemet's membrane.

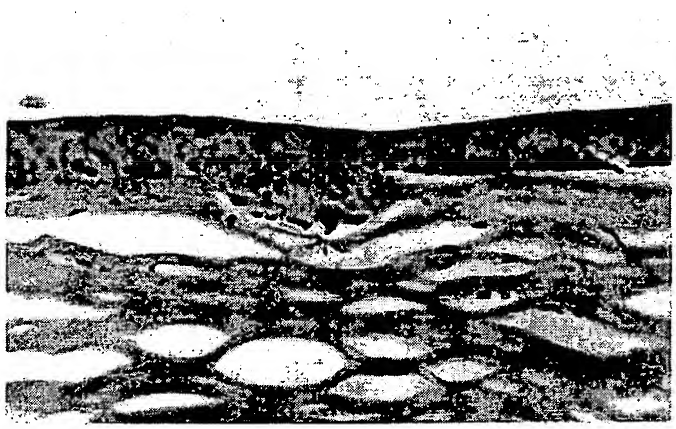

Fig. 6. Epithelial facet at the site of a healed 10-day-old corneal lesion. The anterior stroma contains fibroblasts and inflammatory cells. Separation of stromal lamellae is artifactitious. (Hematoxylin and eosin; ×500.)

Results

In the first series of exposures using the direct output beam of the laser, corneal energy densities ranging from 0.1 to 1.0 j./cm.[2] were achieved. No evidence of corneal, lenticular, or chorioretinal injury could be detected at these energy levels. In the subsequent series of exposures with the laser beam focused at the cornea, ocular damage occurred and was limited to the cornea.

The minimum criterion for damage was defined as the presence of a corneal lesion seen by slit lamp biomicroscopy at 60 minutes following exposure. Near-threshold corneal lesions were characterized by a shallow depression of the epithelial surface with localized epithelial edema and mild fluorescein staining. Discrete grayish opacifications of Bowman's membrane and the anterior corneal lamellae occurred at the impact site. More severe lesions showed a whiter opacification down to the deeper stromal layers and, in some cases, wrinkling of Descemet's membrane (Fig. 5). No lens or fundus changes were noted, and anterior chamber reaction was absent. The epithelial defects healed in the course of 1 to 3 days, while the stromal opacification remained essentially unchanged at the end of 3 weeks.

In fresh corneal lesions the histopathologic changes were characterized by localized coagulation necrosis of the epithelium, Bowman's membrane, and anterior stromal layers. Healed lesions showed proliferation of the corneal epithelium and the formation of collagenous scar tissue in

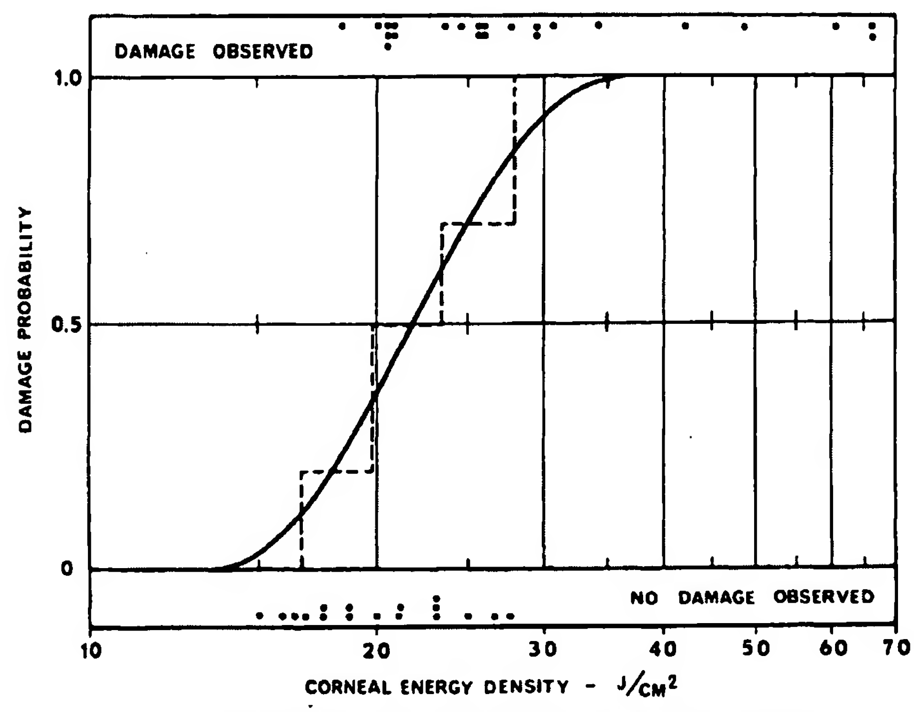

Fig. 7. Corneal damage probability plotted as a function of corneal energy density for Q-switched erbium laser. All exposures included were delivered in a single Q-switched pulse of 50 nanoseconds duration.

the anterior stroma (Fig. 6). No evidence of lenticular or retinal damage was found on careful examination of serial sections.

The probability of corneal damage as a function of incident corneal energy density is shown in Fig. 7. Each exposure in the focused-beam series was entered at its calculated energy density above or below the graph according to whether corneal damage was observed. A histogram was constructed by dividing the energy density range into equal logarithmic intervals and computing the proportion of damage for each interval (the proportion of damage is equal to the number of exposures producing damage divided by the total number of exposures within the interval). A smooth curve was fitted to the histogram in order to approximate the probability curve for damage over the range of energy

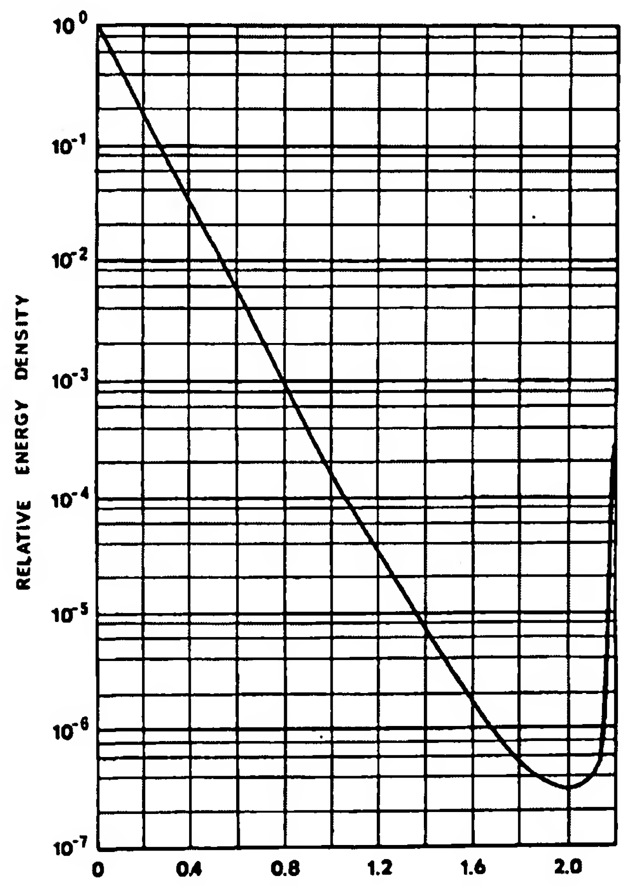

Fig. 8. Theoretical relative energy density distribution in the eye showing the combined effects of focusing and absorption of 1.54μ radiation. This "worst-case" analysis assumes a collimated beam with the eye refracted for infinity at 1.54μ, an 8 mm. pupil, a diffraction-limited retinal spot of 8μ in diameter and a 2.2 cm. axial length from the anterior corneal surface to the retina. The absorption coefficient of pure water is used (10 $cm.^{-1}$).

densities tested. The 0.5 damage probability obtained from the curve was 21 j./cm.^{2}. All exposures to energy densities greater than 30 j./cm.^{2} produced injury, whereas no injury was detected below 17 j./cm.^{2}.

Discussion

This report represents the first published data on the ocular effects of the erbium laser. In order to produce any ocular injury with the erbium laser at energy outputs currently achievable, it was necessary to increase the energy density at the cornea by focusing the beam onto the cornea. Under these conditions observable ocular damage was restricted to the cornea. The use of a focused beam, however, does not result in the "worst case" situation for retinal damage; that is, a minimal retinal spot size produced by the eye from a collimated beam. When the direct collimated beam of the erbium laser was used, a corneal energy density of 1 j./cm.^{2} did not produce any observable retinal damage. It is likely that even with much greater corneal energy densities no retinal damage would occur because of the attenuation through the eye at the erbium wavelength (Fig. 8). This is in sharp contrast to lasers operating in the visible and near-visible portions of the spectrum where the combined effects of high ocular transmission and focusing by the eye produce tremendous amplification of the incident energy density.[3] In this respect the erbium laser represents a comparatively "safe" laser.

Corneal damage qualitatively similar to that produced by the Q-switched erbium laser has been described by several groups using the carbon-dioxide laser which operates in the infra-red at 10.6μ.[4-6] These investigations have utilized a continuous-wave carbon dioxide laser and have included exposure durations down to the millisecond range. Before a precise quantitative comparison of carbon dioxide damage threshold values can be made with our data on erbium, experiments with a Q-switched CO_2 laser will have to be performed. Suffice it to say that, based upon the higher absorption coefficient of water at the 10.6μ wavelength (950 cm.$^{-1}$) compared to the 1.54μ wavelength (10 cm.$^{-1}$), one would expect a greater energy absorption per unit volume of irradiated corneal tissue and, thus, a lower corneal damage threshold for the Q-switched carbon dioxide laser.

Dr. Myron Yanoff, University of Pennsylvania, Department of Ophthalmology, assisted in the evaluation of the histopathologic material.

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